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Advanced air distribution for minimizing airborne cross infection in aircraft cabin

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SUMMARY

The performance of personalized ventilation combined with local suction at each seat was studied for the purpose of minimizing airborne cross-infection in vehicle compartments. Experiments were carried out in a simulated aircraft cabin section (3 rows, 21 seats). One breathing thermal manikin simulated “infected” polluting passenger and another simulated “exposed” passenger. Personalized ventilation supplied clean air at 10 L/s from front against manikins’ face. Air was sucked at 10 L/s by a suction system of two nozzles positioned on the sides of “infected” manikin’s head. The cabin was ventilated at 180 L/s. The concentration of Freon mixed with air exhaled by the “infected” manikin was measured. The personalized flow pushed the contaminated exhaled air backwards where it was pulled by the suction and exhausted before mixing with the cabin air. This resulted in substantial decrease of the tracer gas concentration in the air inhaled by the “exposed” manikin and the exhausted cabin air.

KEYWORDS

Airborne disease transmission, push-pull ventilation, exhaled air removal, exposure reduction, vehicle compartment

1 INTRODUCTION

Airborne transmission of infectious diseases due to respiration activities (breathing, coughing, sneezing) is a serious problem, especially in densely occupied spaces such as vehicle compartments (airplanes, trains, busses and cars), theaters, etc. Advanced air distribution, such as personalized ventilation (PV) aiming at supply of clean air to the breathing zone of occupants has been studied (Melikov 2004). It has been reported that the use of PV can decrease the exposure to indoor pollution including infectious agents generated due respiration activities (breathing, coughing and sneezing) of sick people. Cermak and Melikov (2007) reported that desk installed PV, supplying clean air from front and against the face of the seated person, may reduce substantially the risk of cross infection compared to the case of total volume air distribution alone (e.g. mixing air distribution, etc.). Bolashikov et al. (2010) and Melikov et al. (2012) reported that as much as 99% clean PV air in inhalation was obtained when it was supplied from the back and tangentially from seat-headrest incorporated nozzles positioned on the two sides of the headrest. Niu et al. (2007) reported on substantial increase of the portion of clean air in inhaled air when it was supplied from a nozzle attached to the seat armrest and discharging air against passenger’s face. Zhang and Chen (2007) and Zitek et al. (2010) reported on improved air cleanness at the breathing zone of airplane passengers by use of PV with air supply nozzle placed at the back of the front seat and discharging air toward the face. Nielsen et al. (2007) reported on improved inhaled air quality by supply of clean air from the cushion and the back rest of a seat. Bolashikov et al. (2003) and Zhu et al. (2008) reported on PV with an air supply nozzle installed in the microphone casing of a headset unit providing 80% and more of clean air in the air inhaled by the user. The advantage of these designs is that clean air is provided to the breathing zone of occupants

and this leads to decrease the exposure to airborne viruses and the risk of airborne transmission between occupants. The drawback of all these PV designs is that they do not help for source control, i.e. viruses and bacteria present in air exhaled and coughed by sick persons remain in the surrounding air.

Dygert and Dang (2010) reported on a method of source control through the use of seat attached suction orifices aiming at ingesting the individual's thermal plume (the carrier of bio-effluents) before it can mix with the surrounding air. They evaluated the effectiveness of various seat-integrated suction designs in minimizing passenger exposure to bio-effluents in a typical coach-class aircraft cabin with mixing ventilation. Results indicate a reduction in personal exposure to bio-effluents from neighboring passengers of up to 65% when overhead suction was used. However the method is not efficient for removal of air exhaled or coughed by sick people that may carry airborne viruses and bacteria.

A novel air distribution method aiming at control of exhaled air transportation was developed and studied. The method is based on “push and pull” principle and applicable in densely occupied spaces with seated people, such as commercial airplanes, trains, busses, theaters, etc. It is schematically shown in Figure 1. The location of seat installed air supply and exhaust terminal devices is used for control the airflow interaction at the breathing zone leading to increase cleanness of the inhaled air and removal of the contaminated exhaled air at the seat before it is mixed with the surrounding air, i.e. leading to pollution decrease in the cabin air. Clean air is supplied from the back of the front seat against the breathing zone of the passenger seated behind. The clean air penetrates the free convection flow existing in front of his/her body and is inhaled before mixing with the surrounding polluted cabin air. At the same time the supplied personalized airflow interacts with the exhaled air and pushes it back toward seat incorporated exhaust nozzles located on the two sides of the seated person. Thus the polluted exhaled air is exhausted at the location where it is generated before mixing with the surrounding air.

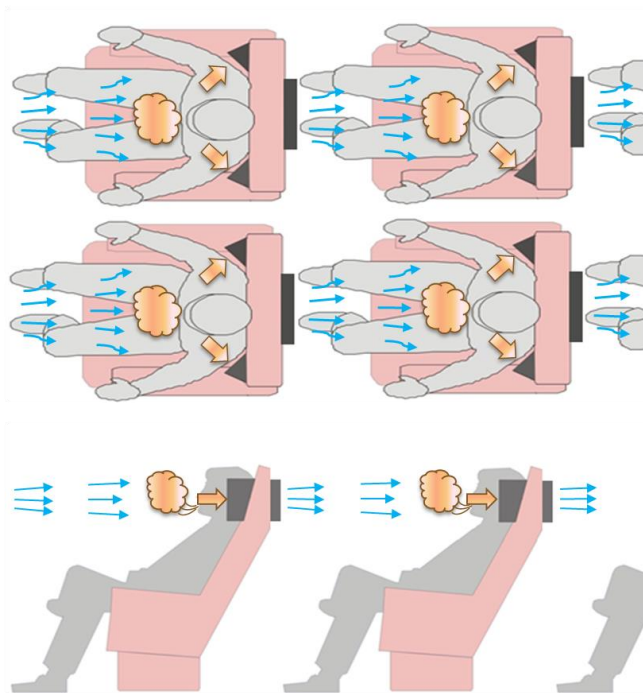


Figure 1. Advanced air distribution at seat aiming at exhaled air removal at the source.

2 METHODS

The experiments were performed in a simulated aircraft cabin section (length – 3.2 m, volume - 28.5 m³) with 3 rows of 7 seats each. The shape, volume and appearance of the simulated aircraft cabin as well as the inner wall surface temperature were similar to real aircraft cabin.

Two breathing thermal manikins with body shape of an average Scandinavian female (1.68 m tall) were used to simulate passengers. The surface temperature of manikins' body segments was kept as the skin surface temperature of human body in state of thermal comfort. The manikins were dressed with fit clothing (thermal isolation of 0.52 clo). The manikins were equipped with artificial lungs and resembled respiration of a seated person (Melikov and Kaczmarczyk, 2007). During the experiments one of the manikins was used as “infected” person and the other as “exposed” person. The air exhaled by the “infected” manikin was mixed with tracer gas (Freon 134A) to mimic infectious agents. A pulmonary ventilation of 6 L/min and 10 s⁻¹ breathing frequency and breathing cycle of 2.5 s inhalation, 2.5 s exhalation and 1 s break was simulated. The exhalation was performed through the mouth and inhalation through the nose. The temperature of exhaled air was adjusted to be approximately 34°C.

The cabin ventilation system allows for supply of only outdoor air, outdoor air mixed with re-circulated air and only re-circulated air. An authentic slot diffuser located in the middle of the ceiling is used to supply air symmetrically over the ceiling to the two sides of the cabin. The air exhaust terminals (perforated pipe) are located on the two sides along the cabin walls near the floor. The supply and exhaust air flow rates are controlled separately (with accuracy of $\pm 2\%$ of the actual flow) as well as the temperature of the supply air and cabin air (accuracy ± 0.2 °C) and relative humidity (with accuracy of $\pm 3\%$). In the present experiment 100% outdoor air was used to ventilate the cabin.

Two of the seats in the cabin were equipped with personalized ventilation (PV) systems. The PV systems supplied clean outdoor air through circular air supply terminal devices (ATD) with diameter of 0.12 m. The ATD were installed on the back of the seats in front of the two manikins and supplied air toward their face as shown in Figure 1. The ATD were designed to generate low turbulent flow. The temperature and flow rate of the supplied personalized air was controlled. Local exhaust (“Suction”) system consisting of two nozzles positioned on the sides of the head of the “infected” manikin was installed. The Suction aimed at evacuating the contaminated air exhaled by this manikin before it is mixed with the cabin air. The two nozzles of the Suction were with identical rectangular shape (0.08 × 0.13 m²). Both nozzles were set at an angle of 45° at the two sides of occupant's head to follow the shape of the headrest. The flow rate sucked through the nozzles was controlled.

During the experiments two of the cabin seats were occupied by the manikins. Heated dummies (70 W) were placed on the remaining seats to simulate the heat load and thermal plum generated by passengers. In order to achieve more realistic background cabin air distribution small fans positioned on the seat in front of each dummy were used to simulate personalized flow from front for these “passengers”.

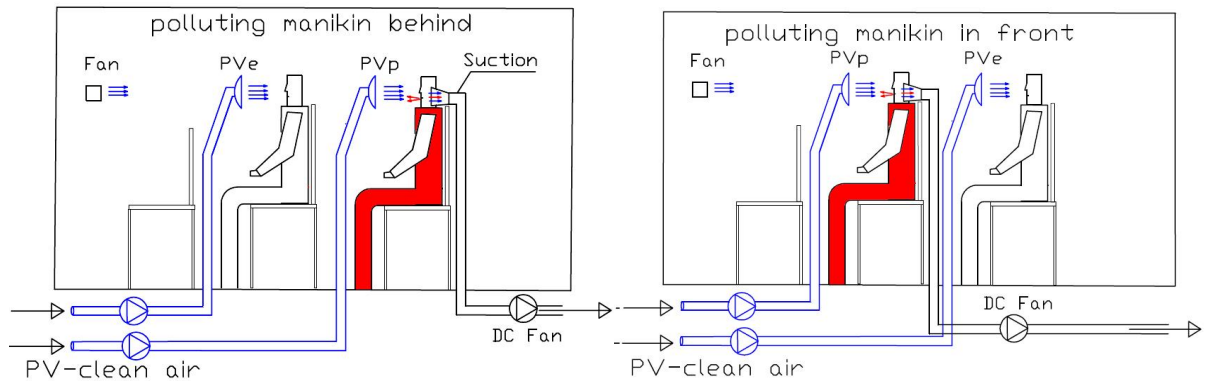


Figure 1. Configuration of thermal manikins and the PV ATD and Suction in the cabin: a) “infected” passenger behind the “exposed” passenger; b) “infected” passenger in front of the “exposed” passenger.

The two PV systems with identical air terminal devices were employed in various combinations with the Suction. Measurements were performed for 2 configurations (Figure 1): when the “infected” manikin was behind the exposed manikin and when it was in front of the exposed manikin. During the experiments the manikins occupied only the two middle seats of the second and third rows in the cabin.

The measurements were conducted at 5 different operating conditions (cases): 1) **all OFF**: personalized ventilation of the exposed manikin (PVe) is OFF, personalized ventilation of the polluting manikin (PVp) is OFF and Suction is OFF. This combination is considered as reference case; 2) **Suction + PVp**: PVe is OFF, PVp is ON and Suction is ON; 3) **Suction + PVe**: PVe is ON, PVp is OFF and Suction is ON; 4) **PVe only**: only PVe is ON, PVp is OFF and Suction is OFF; 5) **all ON**: both PVe, PVp and Suction are ON.

The airflow rate of the PVp, PVe and the Suction was identical, equal to 10 L/s. The efficiency of the PVs at lower flow rate was also studied but is not reported in this paper. The total volume supply flow rate of the background cabin ventilation was kept constant at 180 L/s. A slight overpressure of about 7 Pa was maintained inside the cabin. The supply air kept the cabin air temperature at 23 °C. Slightly higher temperature of 25 °C was maintained for the personalized air in order to simulate the heat gain from use of local fan or cleaning device. The humidity in the cabin was not controlled. It varied in the range 20 – 30 % RH. The fans on the seats with the dummies were switched ON during all experiments.

Freon concentration was measured after steady state conditions were reached in the cabin. For each of the studied cases tracer gas concentration was identified (average of at least 10 repeated measurements) at six locations: sampling tube attached at the face between exposed manikin’s mouth and nose (less than 3 mm from the surface) representing tracer gas concentration in the air inhaled by the exposed manikin (Melikov and Kaczmarczyk, 2007); in the exhaust air, i.e. the concentration of the air inside the cabin assuming complete mixing; in the PVp and PVe ducts just before the air supply devices, i.e. the concentration of tracer gas in the supplied personalized air; in the Suction; in the air supplied from the ceiling diffuser of the background cabin ventilation system.

The performance of the two PV systems and the Suction was tested with regard to the contaminant (Freon) concentration in the air inhaled by the exposed thermal manikin, C_e . The concentration C_e was compared with the concentration in the air inhaled by the exposed

manikin, C_r , when neither the PVs, nor the Suction was operated, i.e. the reference case **all OFF**. An index, named Relative Inhaled Concentration (RIC) is used in the present paper to present and compare the obtained results. The index is defined as: $RIC = C_e/C_r$.

3 RESULTS

Figure 2 (left) shows the RIC in the case when the polluting manikin was behind the exposed manikin and Figure 2 (right) when the polluting manikin was in front of the exposed manikin.

In Figure 2 the RIC obtained under the studied conditions (cases) is compared. The use of the PVs and the Suction decreased the RIC, i.e. decreased the portion of the tracer gas exhaled by the polluting manikin in the air inhaled by the exposed manikin. The RIC decreased by approx. 35-40 % when the Suction and the PVp were used but the PVe was not used. The use of the PVe caused dramatic decrease of the RIC, between 72 and 77%. The RIC decreased 5 to 7 times when all studied systems were employed. The results show that the positioning of the manikins (polluting manikin behind or in front of the exposed manikin) had little impact on the tracer gas concentration in the air inhaled by the exposed manikin. The RIC was slightly lower when the polluting manikin was seated in front of the exposed manikin. The reason might be that the airflow generated by the small fans positioned in front of the dummies (simulating personalized ventilations systems for the rest of the cabin passengers) directed the contaminated air exhaled by the “infected” manikin towards the exposed manikin sitting behind. The results also show that the use of the Suction without the PVp was not efficient in evacuating the contaminated air exhaled by the polluting manikin. The RIC values obtained in the case “Suction+PVe” and “PVe only” were rather close.

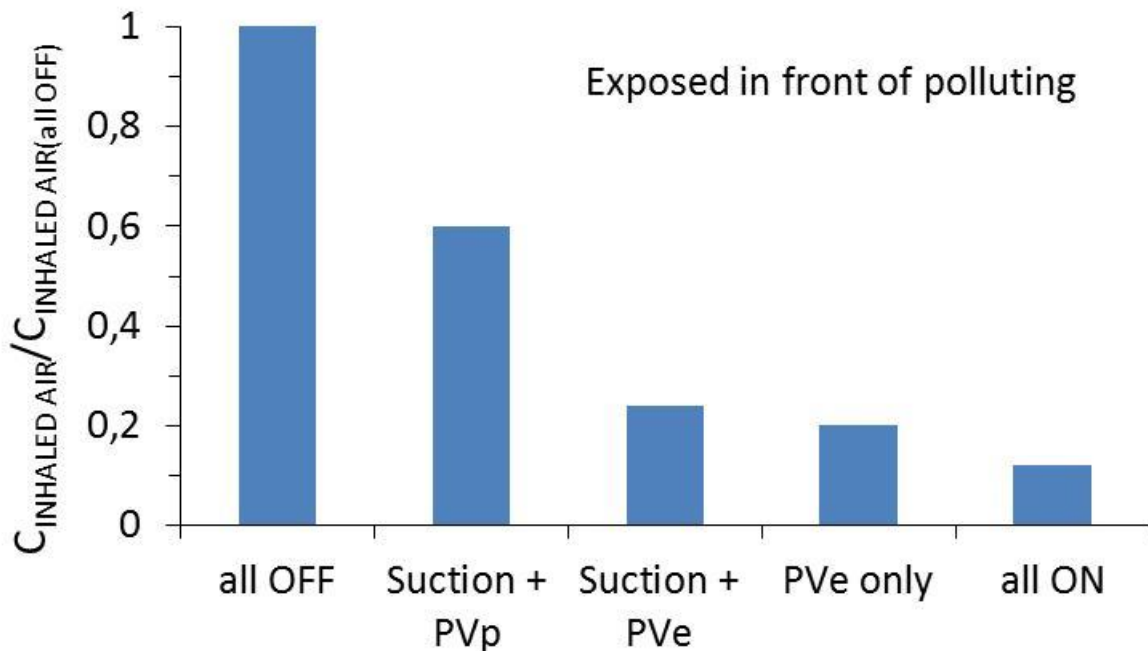


Figure 3. Relative concentration of tracer gas exhaled by the polluting manikin in the air inhaled by the exposed manikin when it is seated in front of the polluting manikin.

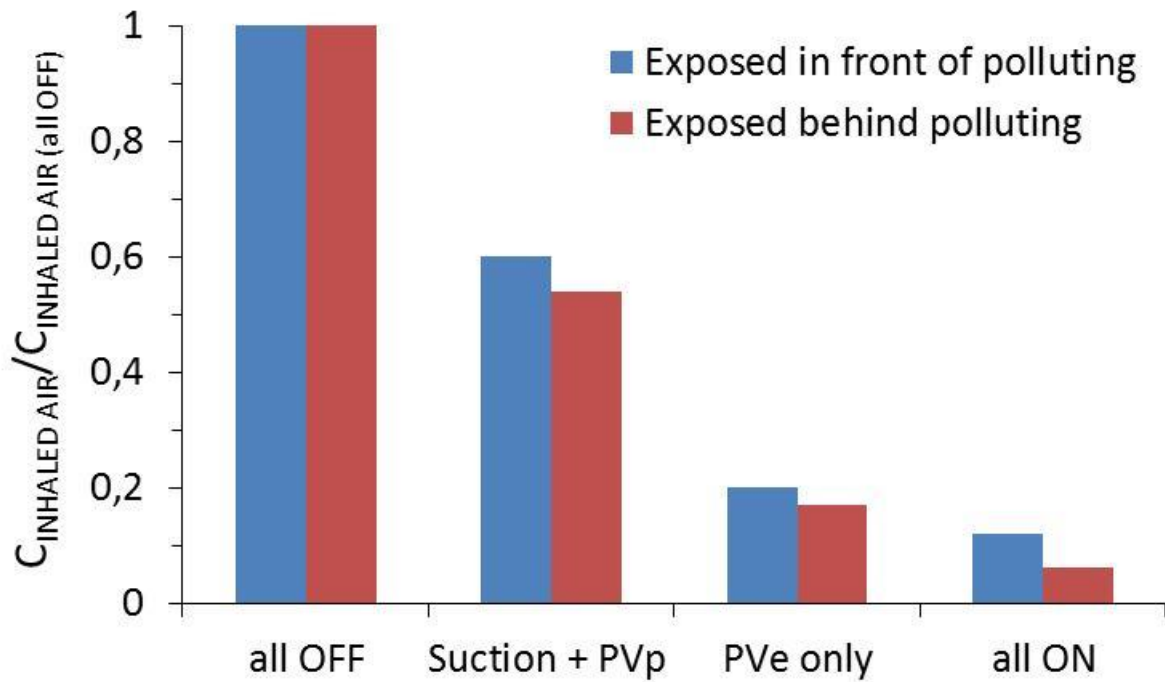


Figure 4. Comparison of concentration of tracer gas exhaled by the polluting manikin in the air inhaled by the exposed manikin when it is seated in front and behind the polluting manikin.

Figure 3 compares the tracer gas concentration measured at the cabin exhaust in four of the studied cases: all OFF, PVe only, Suction+PVp and all ON. The results clearly indicate that the use of the Suction combined with the PVp (**Suction+PVp**) lead to great decrease (approx. 42%) in the value of the RIC in comparison with the case “**all OFF**”. The use of the PVe did not affect the tracer gas concentration in the exhaust cabin air. It may be concluded that the use of the Suction in combination of the PVp was the reason for the decrease of the tracer gas concentration in the exhaust air. The same conclusion may be valid for the cabin air as well, because the measurements in the exhaust air were not affected by the positioning of the manikins which may be indicator for a good mixing of the cabin air.

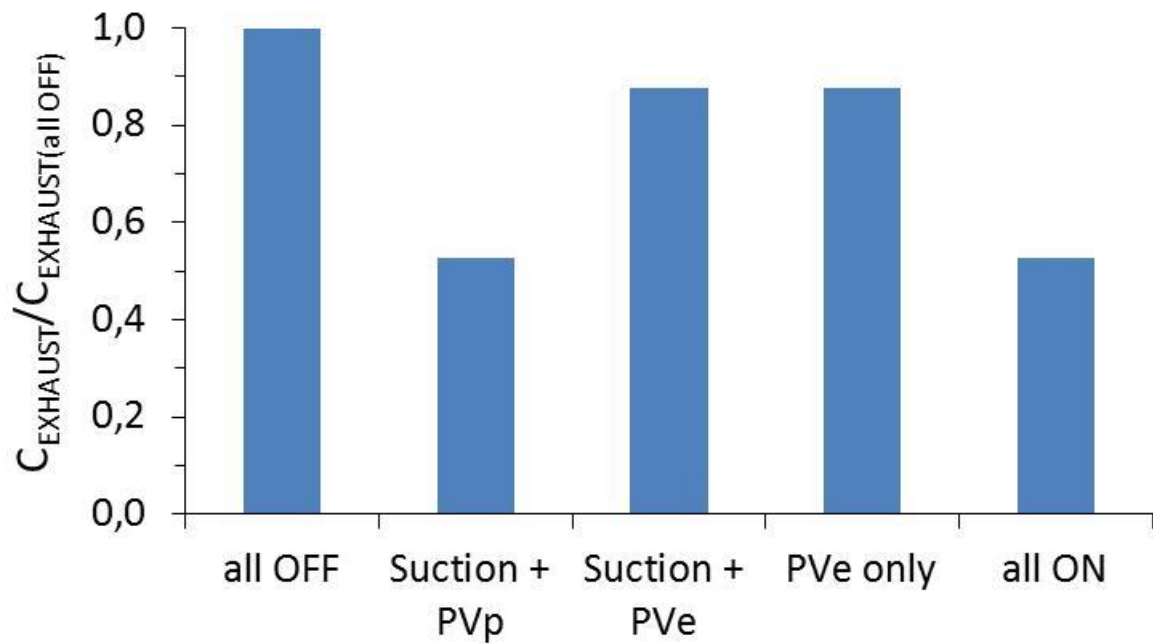


Figure 6. Relative concentration of tracer gas exhaled by the polluting manikin in the cabin exhaust air at the studied cases

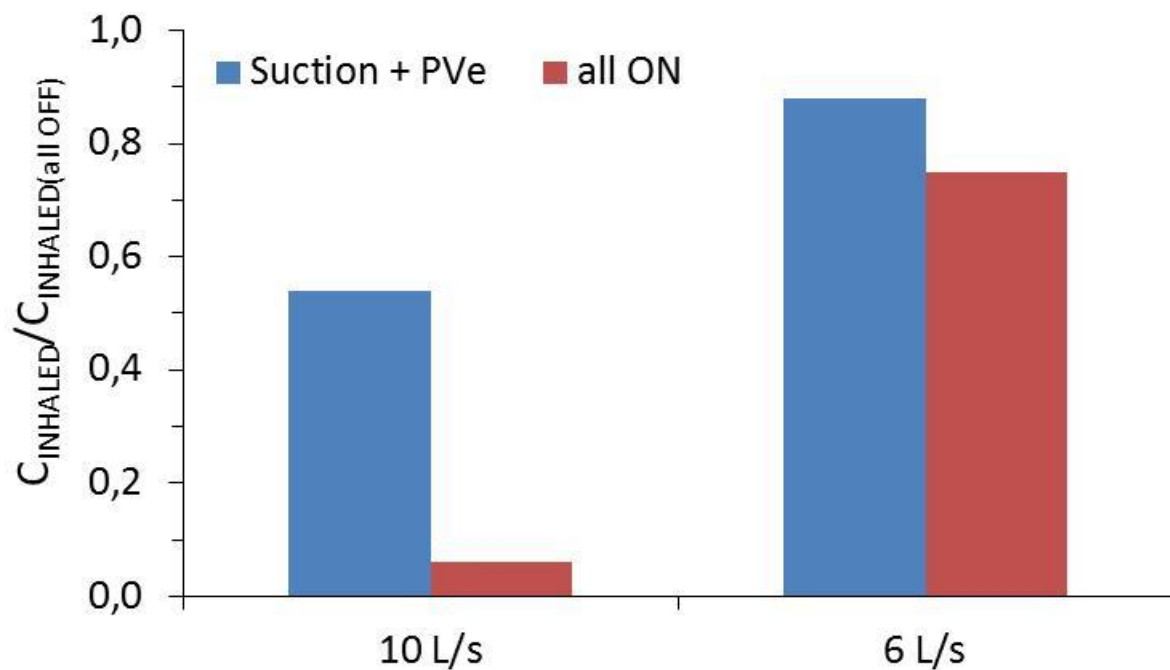


Figure 7. Relative concentration of tracer gas exhaled by the polluting manikin in the air inhaled by the exposed manikin when it is seated in front of the polluting manikin. Results obtained at 10 L/s and 5 L/s in two of the studied cases are compared.

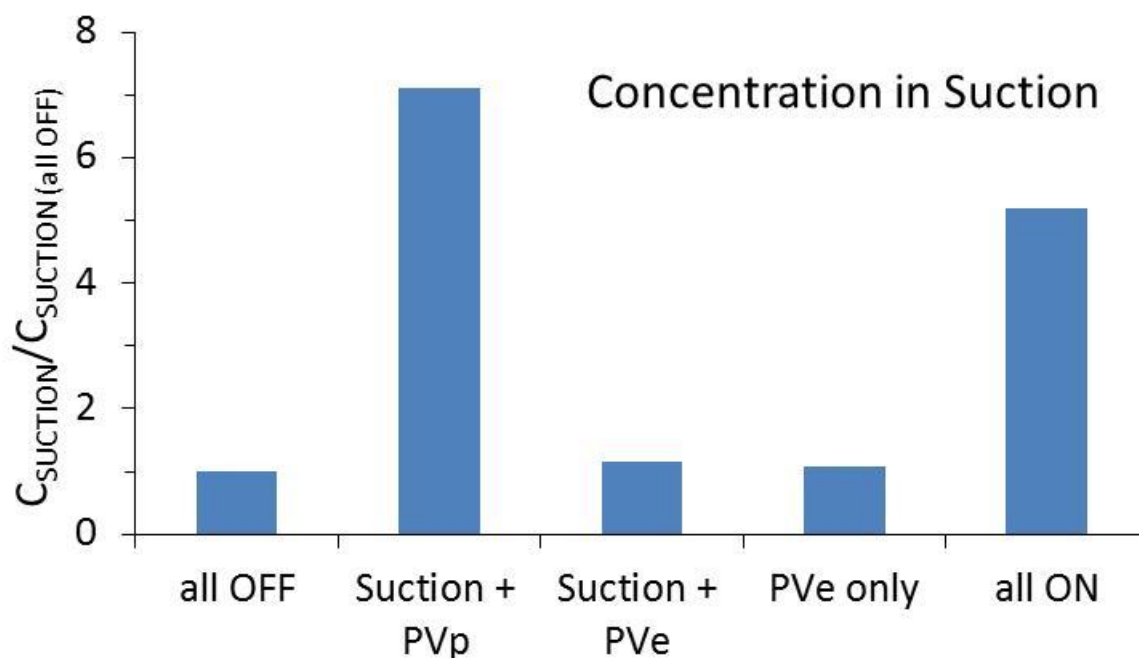


Figure 8. Relative concentration of tracer gas exhaled by the polluting manikin in the suction air at the studied cases.

4 DISCUSSION

Advanced air distribution, such as personalized ventilation, has been used for improving inhaled air quality and decreasing the risk of airborne transmission of diseases. However the reported methods (discussed briefly in the introduction) are not able to provide pollution source control, i.e. users may breath clean air when using the PV but contaminated exhaled air (may be contaminated with pathogens) remains in the space. Melikov et al. (2010, 2011) reported on hospital bed ventilation based on the “push and pull” air distribution method based on two important considerations: 1) control of the interaction between the personalized flow and the respiration flow and 2) proper location of the local suction. In the present study the “push and pull” air distribution method was found to be efficient when applied in a densely occupied space, i.e. commercial airplane cabin: the concentration of contaminated exhaled air in the background air decreased by 42% when the “push and pull” method was used at 10 L/s flow rate of the supplied personalized and exhaust air. This result suggests decrease in the risk of airborne cross infection. The performance of the method at lower supply and exhaust flow rates will be reported in the future. Yang and Sekhar (2011) reported on application of the method in office environment. They obtained improvement in the cleanness of the inhaled and the background air at relatively high flow rates: 8 – 16 L/s from the PV and 25 – 75 L/s for the suction air. Use of personalized flow with low mixing with the surrounding air, careful positioning of the suction with regard to the personalized flow and proper design of the seat/chair will improve the performance of the “push and pull” method at much lower suction flow rates. As already discussed the “push and pull” method can be used efficiently in densely populated spaces such as vehicle compartments, theaters, etc. as well as in call centers, receptionists, waiting rooms, meeting rooms, dealer rooms, etc., i.e. in spaces where occupants do not move much for relatively long time.

The substantial decrease of the polluted exhaled air in the background of the cabin (decrease by 42%) with the studied ventilation strategy suggests that under some conditions energy may be saved. This needs to be studied.

5 CONCLUSIONS

The use of personalized ventilation combined with local suction at each seat showed to be efficient when applied in an airplane cabin. The PV flow of clean air supplied from the back of the seat in front of seated “infected” person pushed backward the contaminated air he/she exhaled to be pulled into the suctions attached to the seat headrest on the two sides of his/her head before mixing with the cabin air. Control of the interaction of the personalized flow and the flow of exhalation at the breathing zone and the location of the suction are important for the inhaled air quality and the source control. The use of the method in practice, especially in densely occupied spaces (airplanes, trans, theaters, etc.) will decrease the exposure to infected exhaled air and this may decrease of the risk of airborne cross infection. The decrease of the background pollution level will require less ventilation which may lead to energy saving.

ACKNOWLEDGEMENT

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6 REFERENCES

- Melikov A.K. 2004. Personalized ventilation. *Indoor Air*, vol. 14 (Suppl. 7), 157-167.
- Melikov A. and Kaczmarczyk J. 2007. Indoor air quality assessment by a breathing thermal manikin. *Indoor Air*, 17 (1), 50-59.
- Melikov A.K, et al. 2012. Seat Headrest-Incorporated Personalized Ventilation: Thermal comfort and Inhaled Air Quality. *Building and Environment*, 47, 100-107.
- Bolashikov Z.D, Melikov A.K, and Kranek M. 2010. Control of the Free Convective Flow around the Human Body for Enhanced Inhaled Air Quality: Application to a Seat-Incorporated Personalized Ventilation Unit. *HVAC&R Research*, 16 (2), 161-188.
- Niu J, Gao N, Phoebe M, and Huigang Z. 2007. Experimental study on chair-based personalized ventilation system. *Building and Environment*, 42, 913-25.
- Dyger R.K. and Dang T.Q. 2010. Mitigation of cross-contamination in an aircraft cabin via localized exhaust. *Building and Environment*, 45, 2015-2026.
- Zitek P. Et al. 2010. Novel personalized and humidified air supply for airliner passengers. *Building and Environment*, 45, 2345-2353.
- Nielsen P.V. et al. 2007. Chair with integrated personalized ventilation for minimizing cross infection. In: *Proc. of the 10th International Conference on Air Distribution in Rooms - Roomvent 2007*, Helsinki, C05, paper ID: 1078.
- Zhang T, and Chen Q. 2007. Novel air distribution systems for commercial aircraft cabins. *Building and Environment*, 42 (4), 1675-1684.
- Melikov, A. et al. 2011. Novel ventilation strategy for reducing the risk of airborne cross infection in hospital rooms. In: *Proceedings of Indoor Air 2011*, Austin, USA, paper1037.
- Melikov, A. et al. 2010. Experimental investigation of performance of a novel ventilation method for hospital patient rooms, In: *Proceedings of the 21st Congress of International Federation of Hospital Engineering (IFHE)*, Tokyo, November 17th to 19th, 2010.
- Yang, J. and Sekhar, C. 2011. Computational analyses of the performance of personalized ventilation system in conjunction with personalized exhaust. In: *Proceedings of Roomvent 2011*, Trondheim, June 19-22, 2010, paper no. 257.